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# OBLIQUE–WING SONIC BOOM

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An investigation was conducted to determine the magnitude of the groundtrack overpressures generated by an oblique-wing transport cruising at Mach 1.4 at 13,800 meters (45,000 ft.). A conventional swept-wing configuration was included in the study to provide a basis of comparison for the oblique-wing configuration. The results of the investigation have shown that the oblique-wing configuration produces less sonic boom overpressure at cruise lift coefficient than the swept-wing vehicle.

## SUMMARY

An investigation was conducted to determine the magnitude of the groundtrack sonic boom overpressure generated by an oblique-wing transport cruising at Mach 1.4 at 13,800 meters (45,000 ft.). A conventional swept-wing configuration was included in the study to provide a basis of comparison for the oblique-wing aircraft. Near field pressure signatures were obtained during wind tunnel tests of models of both configurations. These signatures were extrapolated to flight distances to provide estimates of groundtrack overpressures.

The results of the study have shown that the oblique-wing configuration produces less sonic boom overpressure at cruise lift coefficient than the swept-wing vehicle.

The oblique-wing model was complete except for engine nacelles whereas the swept-wing model was a simple wing-body combination.

## NOTATION

| | |
|---|---|
| $C_N$ | normal force coefficient |
| h | distance from aircraft or model, meters |
| $l$ | reference length, meters (see figure 1) |
| L/D | lift to drag ratio |
| M | Mach number |
| p | reference pressure, $N/m^2$ |
| RF | reflection factor (2.0 for a perfect reflecting surface) |

$t$ time, milliseconds

$\Delta p$ sonic boom overpressure, $N/m^2$

$\Delta x$ distance along abscissa of pressure signature, meters

## INTRODUCTION

The recent ban on commercial supersonic flight over populated areas has focused attention on air transports designed to operate at speeds slightly less than the threshold Mach number. (The threshold Mach number is the maximum flight Mach number for which complete shock wave refraction will occur above the ground resulting in no ground level sonic boom. Since refraction is caused by wind and temperature gradients, the threshold Mach number depends on wind and sound speeds at the flight and cut-off altitudes.) The threshold Mach number for a standard day without wind is 1.15 for flight altitudes in the stratosphere. When the effect of non-standard atmospheric conditions with typical wind and temperature profiles for different seasons of the year is calculated the threshold Mach number varies from approximately 1.05 to 1.25 depending on aircraft heading and flight altitude. In spite of the relatively large change in threshold Mach number an average ground speed of approximately 335 m/sec (750 mph) can be maintained for transcontinental flights over the United States in any direction regardless of season with a high probability of no ground level sonic boom. This results in average block times of approximately 4 hours for east-west flights in either direction. (A complete discussion of threshold Mach number operation can be found in reference 1.)

Several conventional designs have been proposed in recent years to operate in the transonic flight regime. An unconventional configuration which has received considerable notice is the antisymmetric, oblique-wing configuration (reference 2). In theory, properly designed antisymmetric configurations should have greater aerodynamic efficiency than corresponding symmetric vehicles. The high aerodynamic efficiency can be maintained at speeds greater than the threshold Mach number by increasing the yaw angle of the wing. Furthermore, a transport with a long oblique-wing flying at moderate altitudes at speeds greater than the threshold Mach number would be expected to produce less sonic boom overpressure than a symmetric configuration because the lift is distributed over more of the vehicle length. An investigation was undertaken to determine the magnitude of the groundtrack overpressure generated during operation at speeds greater than the threshold Mach number. The results of that investigation are reported herein.

## MODEL AND TEST CONDITIONS

Drawings of the oblique-wing model and the swept-wing model are shown in figures 1(a) and 1(b) respectively. The leading-edges of the wing and horizontal tail of the oblique-wing model were swept back 65 degrees to maintain subcritical flow over the upper surfaces at Mach 1.4. The swept-wing model represents a configuration designed to produce near field pressure signatures for flight at or below 60,000 ft. at Mach numbers as high as 2.7 (this goal was not achieved at cruise lift coefficient).

The test was conducted in the Ames 2- by 2-foot wind tunnel at Mach 1.4 at a total pressure of 50.8 cm-Hg (20 in-Hg).

The model flow field pressures were measured by a differential pressure transducer connected to a conical static pressure probe (overpressure probe) with a 2-degree included angle. The overpressure probe was attached to the tunnel cross-strut (see figure 2) and had orifices drilled 90 degrees apart around the circumference. The reference side of the pressure transducer was connected to the tunnel wall static orifice.

The normal force was measured during testing by an internal strain-gage balance.

## RESULTS AND DISCUSSION

Wind tunnel pressure signatures for the oblique-wing and swept-wing models recorded at Mach 1.4 are shown in figures 3 and 4 respectively. Signatures were obtained at three different normal force coefficients for each model (the coefficients are based on total wing area). The ratio $(h/l)$ is different for each value of $C_N$ because the distance between the overpressure probe and the longitudinal axis of the model changed with angle of attack. The distance, h, used in the ratio $(h/l)$ is measured from the axis of the overpressure probe to the longitudinal axis of the model at the 50-percent fuselage station. The last shock wave indicated on each oblique-wing signature ($\Delta x/l \sim .95$, figure 3) emanates from the horizontal stabilizer. The trailing shock was not recorded for the oblique-wing signatures because of interference from the reflected bow shock with the aft portion of the signatures. Complete pressure signatures were obtained only for the swept-wing model at the two lower normal force coefficients. This lack of definition of the aft portion of some signatures does not preclude calculation of the maximum groundtrack overpressure for all normal force coefficients for both models since the maximum positive integral of the signature can be calculated in each case.

The groundtrack pressure signatures for both configurations are shown in figures 5 and 6. These signatures were obtained by extrapolating the

wind tunnel data of figures 3 and 4 by the method of reference 3. The groundtrack pressure signatures for the oblique-wing configuration exhibit near field characteristics (multiple shock waves) at all normal force coefficients. The swept-wing configuration produced near field signatures at normal force coefficients of -.01 and .07, whereas the signature at the highest normal force coefficients is nearly an N-wave. The difference in signature form for the two configurations at the highest normal force coefficient is due mainly to the difference in the length of the longitudinal lift distribution.

A summary plot of maximum overpressure vs normal force coefficient for both configurations is shown in figure 7. The maximum overpressure for the oblique-wing configuration is 30-percent less than that for the swept-wing configuration at the highest normal force coefficient. (Current performance analyses indicate that the cruise lift coefficient for the oblique-wing configuration varies between .2 and .4 depending on cruise altitude). The reduction in groundtrack overpressure resulting from increasing the flight altitude from 13,800m (45,000 ft.) to 18,280m (60,000 ft.) was calculated for a normal force coefficient of .25. The results of this calculation are shown in figure 8. Note that the maximum overpressure for 18,280m (60,000 ft.) is 40-percent lower than the overpressure level for 13,800m (45,000 ft.). A reduction in overpressure of this magnitude would not be fully realized in practice because flight at the higher altitude would require a larger lift coefficient, and as noted previously in figure 7 overpressure increases with increasing lift coefficient.

The effect of Mach number on maximum groundtrack overpressure is shown in figure 9. The wind tunnel pressure signature measured at Mach 1.4 and $C_N = .25$ was used to predict the ground overpressures at all Mach numbers of the study. Note the increase in the maximum groundtrack overpressure as the Mach number decreases toward the threshold value. The rate of increase of overpressure shown in the figure was predicted by the modified geometric acoustic theory of reference 3 and is greater, near the threshold Mach number, than observed during ground measurements of sonic boom for full scale aircraft. However, flight over populated areas should not be attempted at speeds too close to the threshold Mach number because small variations in cruise speed or atmospheric conditions may result in the formation of a caustic with some amplification of the ground overpressure due to focusing of the energy.

## CONCLUDING REMARKS

A brief study of the sonic boom characteristics of an oblique-wing transport has been conducted over a Mach number range from 1.15 to 1.4.

The sonic boom level of the oblique-wing configuration at normal force coefficients above .15 was found to be lower than that for a symmetrical swept-wing configuration due to improved near field effects for the oblique-wing.

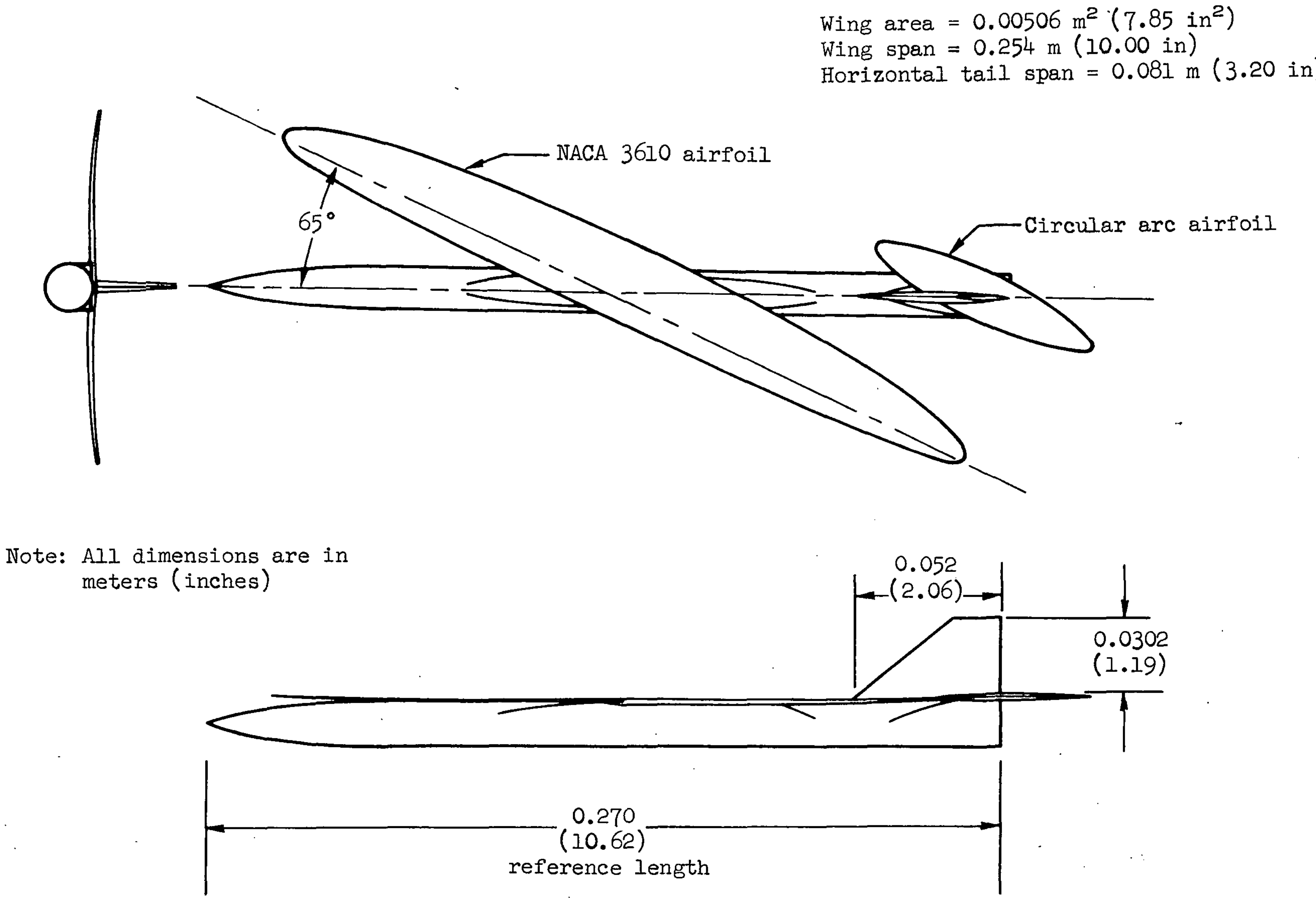
Average block times of approximately 4 hours for east-west transcontinental flights over the United States in either direction are attained without exceeding the threshold Mach number.

## REFERENCES

1. Haglund, George T.; and Kane, Edward J.: Flight Test Measurements and Analysis of Sonic Boom Phenomena Near the Shock Wave Extremity. NASA CR 2167. September 1972.

2. Jones, Robert T.: Properties of Oblique-Wing-Body Combinations for Low Supersonic Speeds. NASA SP-292, 1971.

3. Thomas, Charles L.: Extrapolation of Sonic Boom Pressure Signatures by the Waveform Parameter Method. NASA TN D-6832, June 1972.

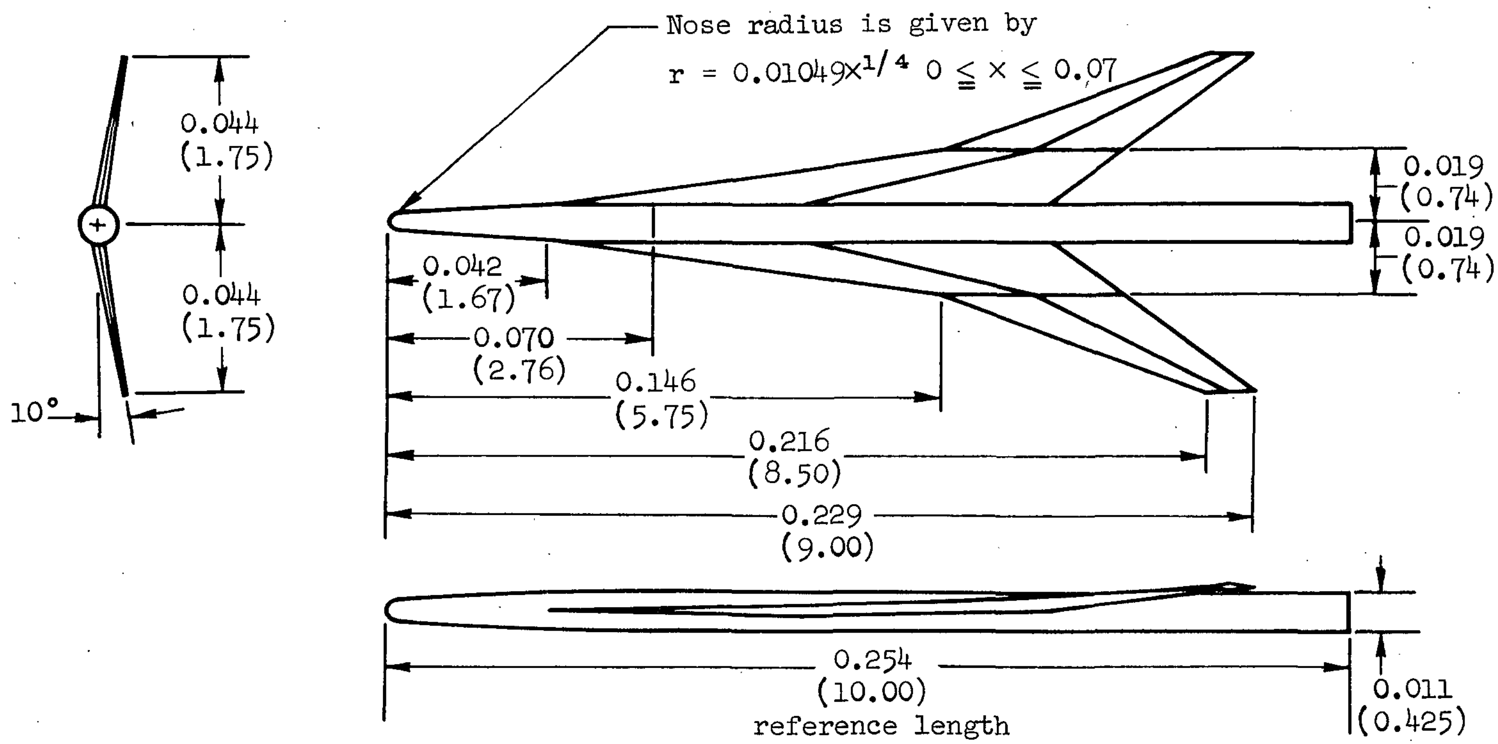



(a) Oblique wing model.

Figure 1.- Model drawings.

Wing area = 0.00539 $m^2$ (8.36 $in^2$)

Note: All dimensions are in meters (inches)




(b) Swept wing model.

Figure 1.- Concluded.

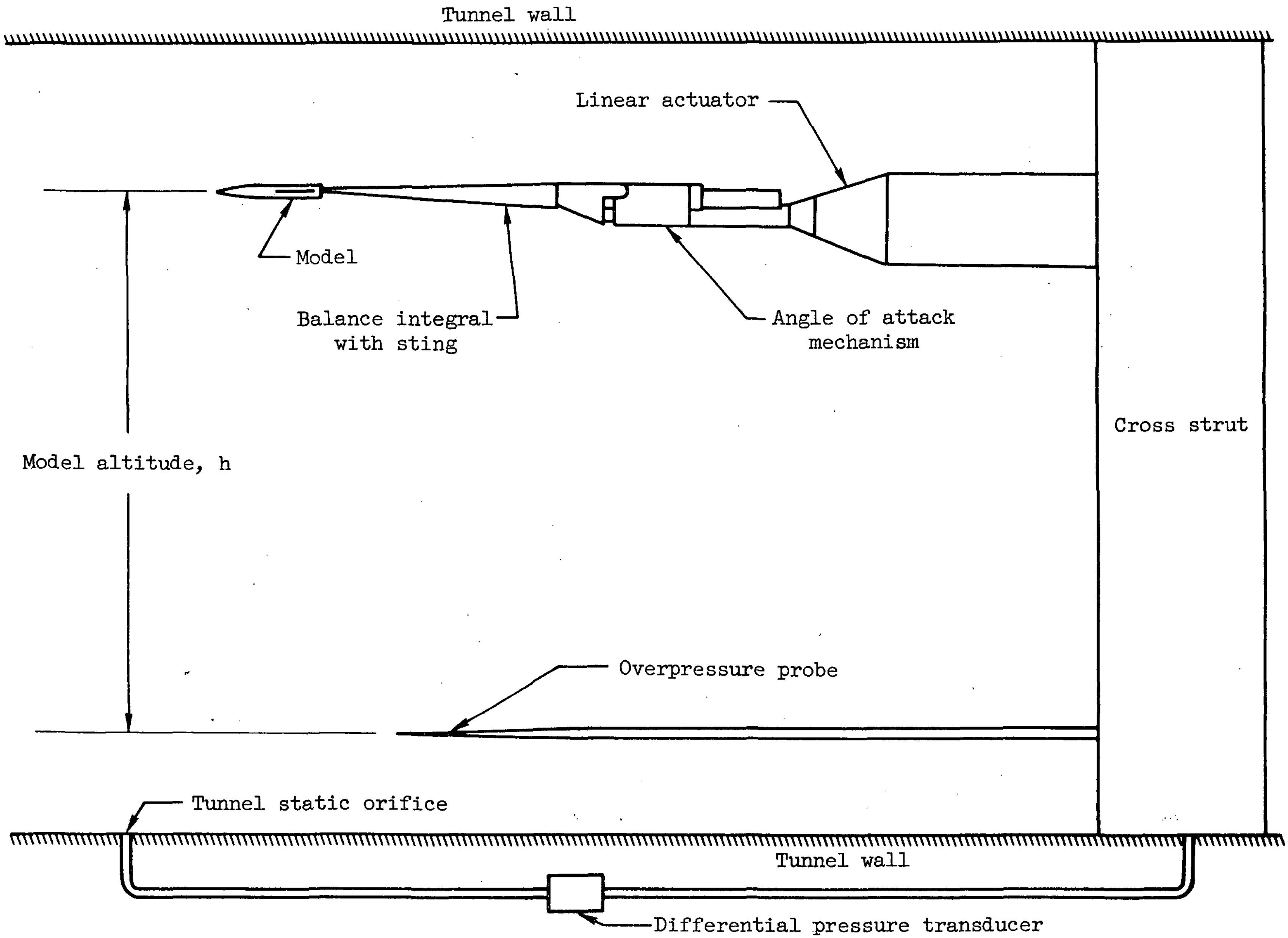



Figure 2.- Wind tunnel apparatus.

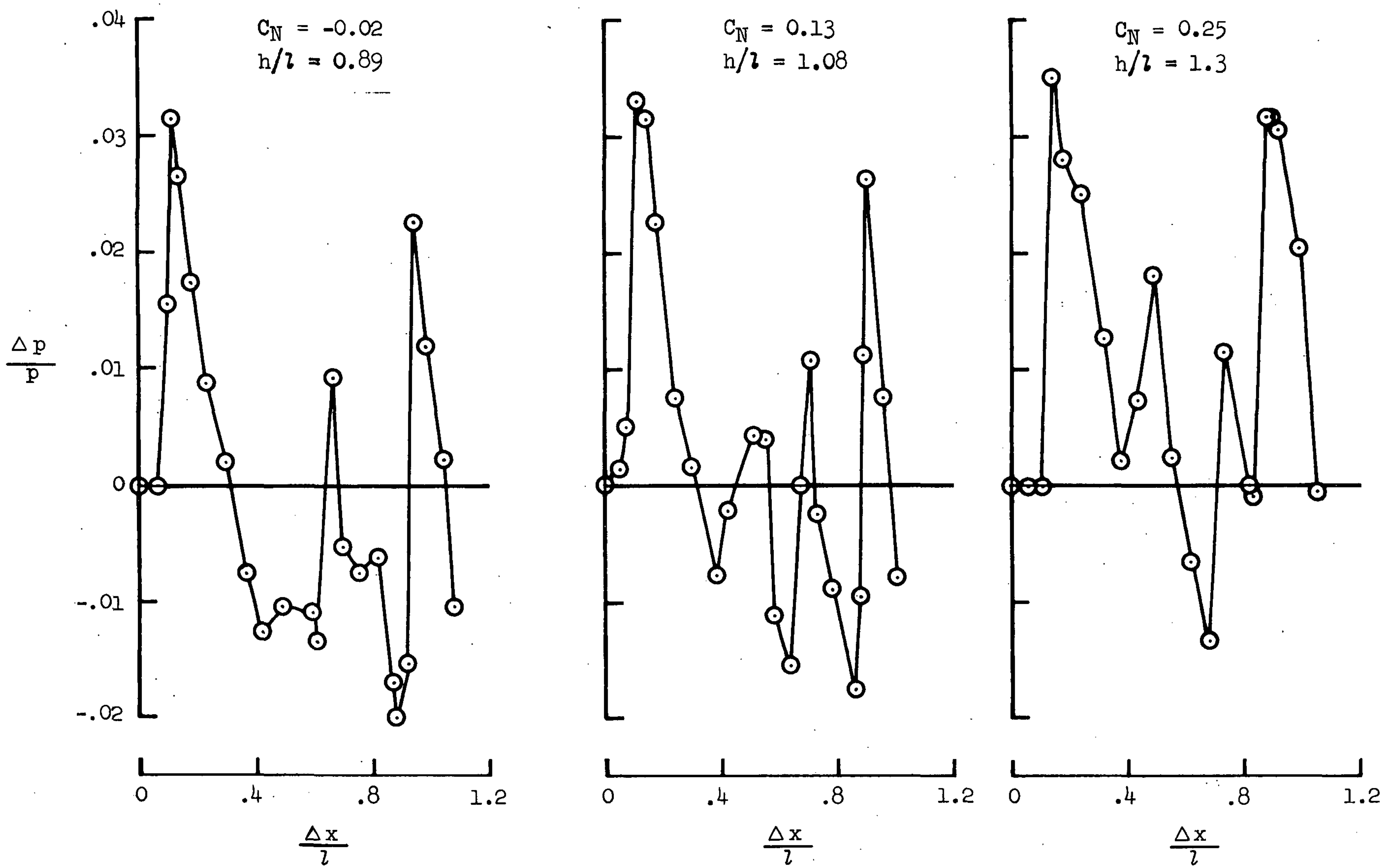



Figure 3.- Wind tunnel pressure signatures for the oblique wing configuration; M = 1.4.

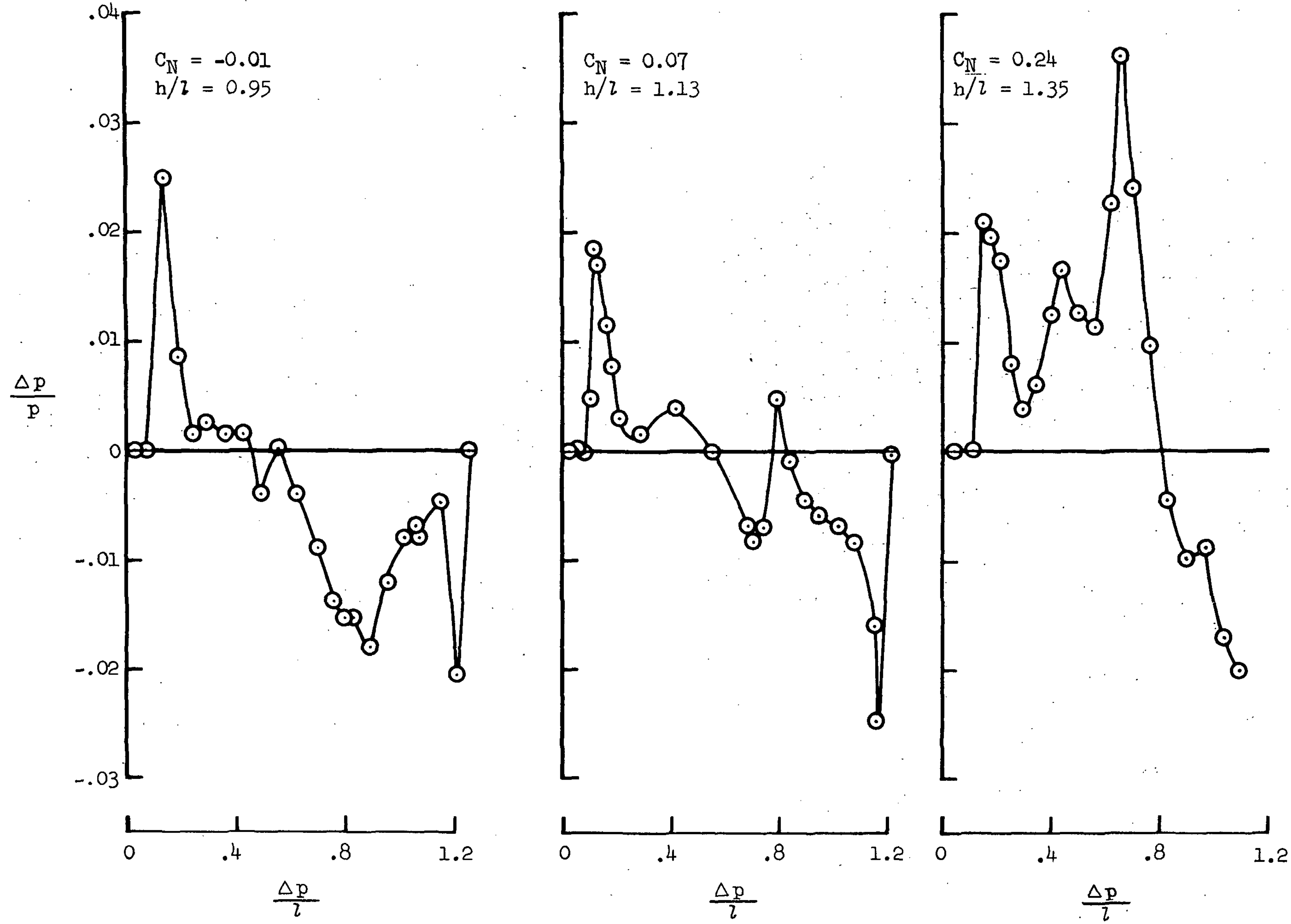



Figure 4.- Wind tunnel pressure signatures for the swept wing configuration; M = 1.4.

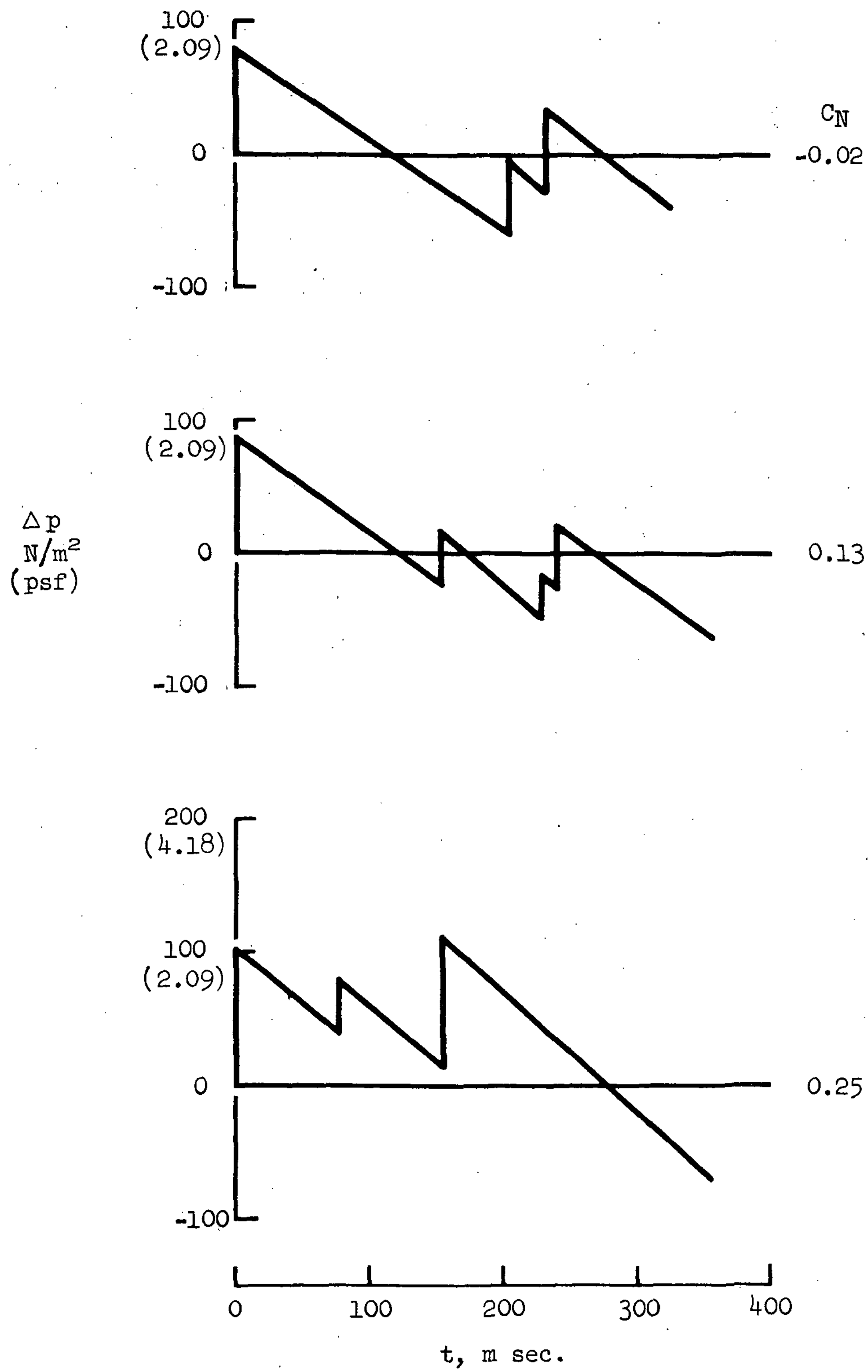



Figure 5.- Groundtrack pressure signatures for the oblique wing configuration; M = 1.4, h = 13, 800 m (45,000 ft), reference length = 91.4 m (300 ft), RF = 1.9.

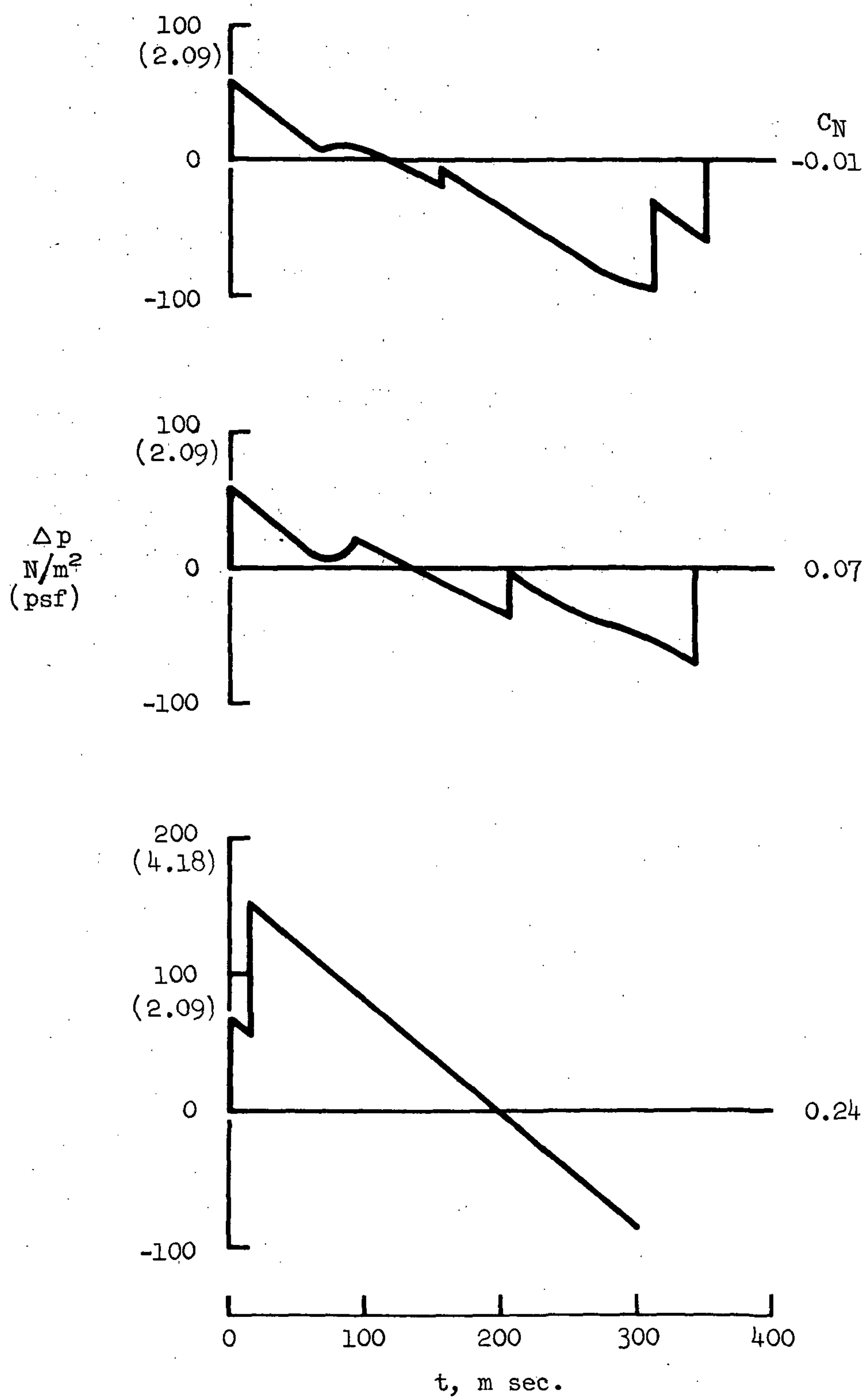



Figure 6.- Groundtrack pressure signatures for the swept wing configuration; M = 1.4, h = 13, 800 m (45,000 ft), reference length = 91.4 m (300 ft), RF = 1.9.

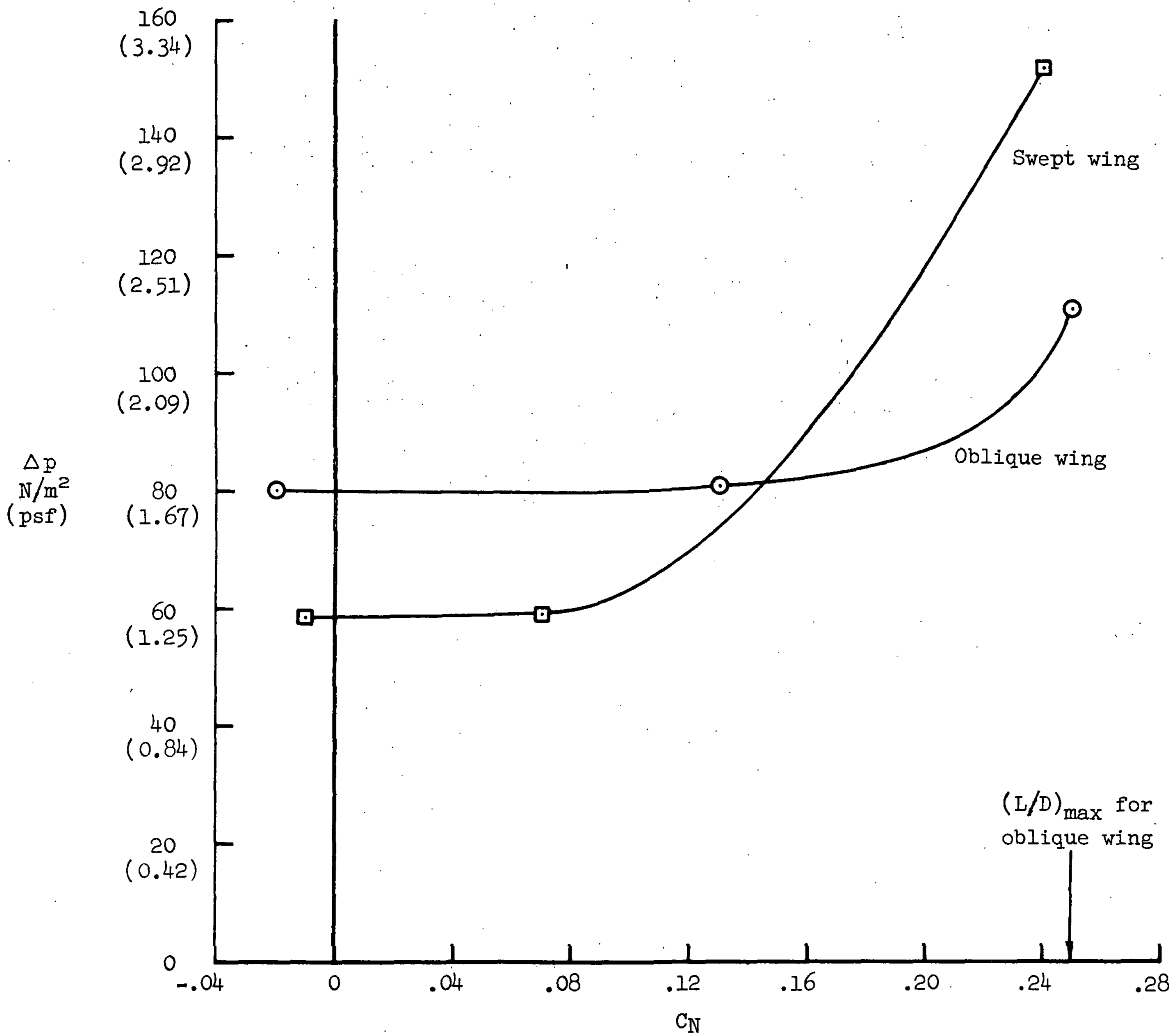



Figure 7.- Effect of normal force coefficient on maximum overpressure; $M = 1.4$, $h = 13,800$ m (45,000 ft), reference length = 91.4 m (300 ft), RF = 1.9.

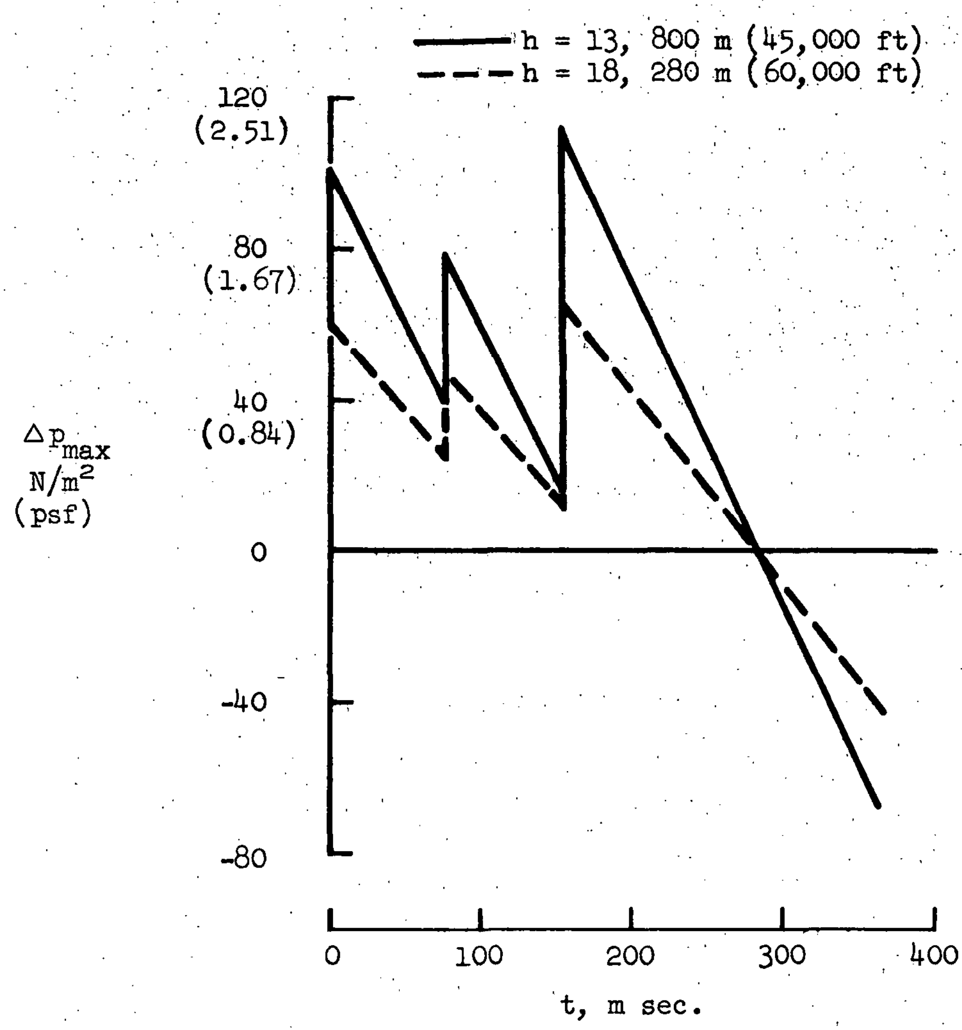



Figure 8.- Effect of altitude on the groundtrack pressure signature of the oblique wing configuration; M = 1.4, reference length = 91.4 m (300 ft), RF = 1.9, $C_N$ = 0.25.

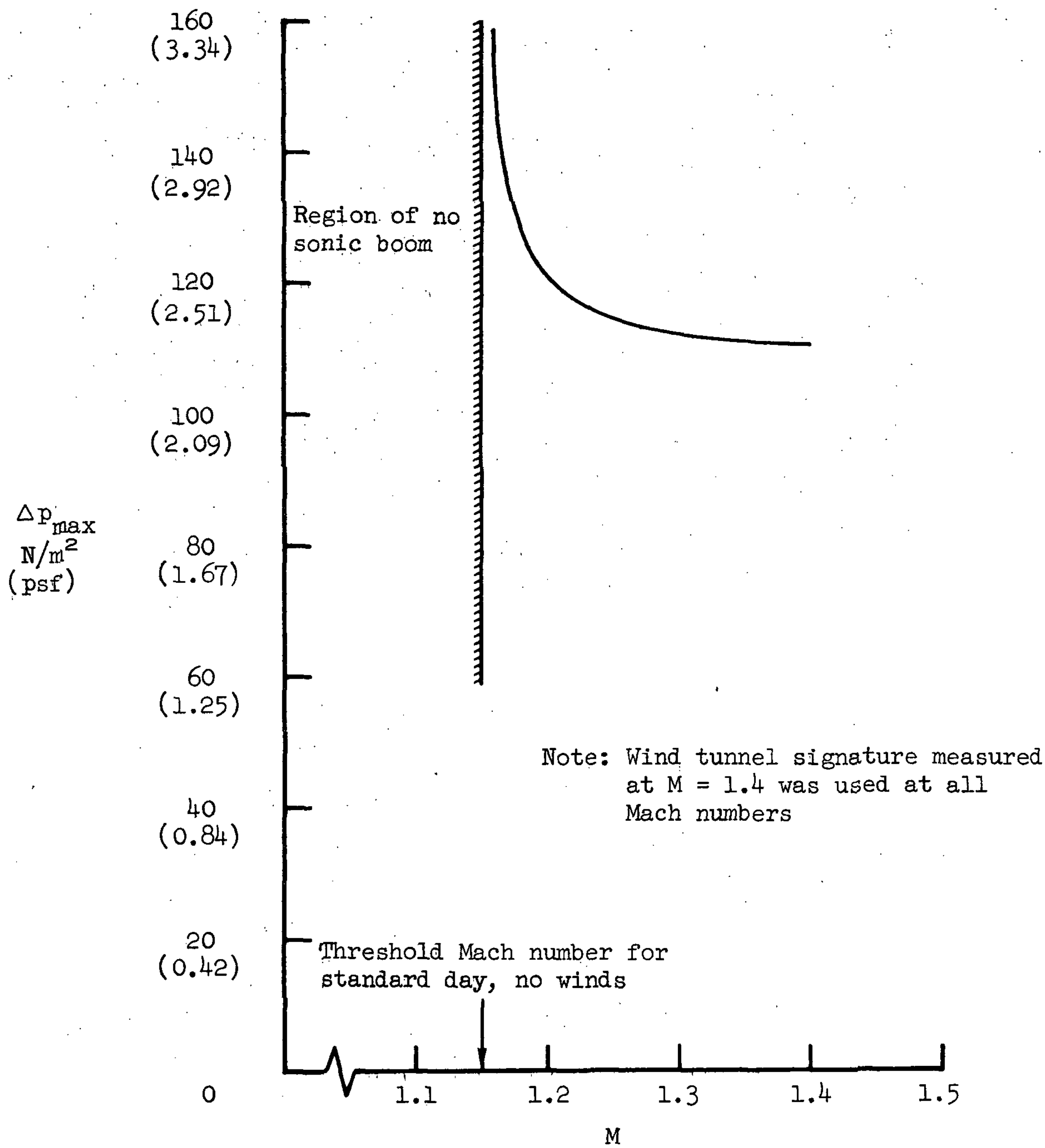



Figure 9.- Effect of Mach number on maximum overpressure of oblique wing configuration; $C_N$ = 0.25, h = 13, 800 m (45,000 ft), reference length = 91.4 m (300 ft).